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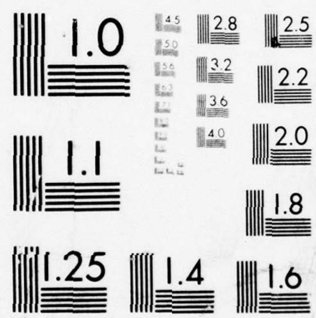
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ACOUSTIC SPECTROMETRY

Samuil Borisovich Stopskiy

Presented in the book are methods for determining the dynamic condition of machines and mechanisms based on the frequency spectrum of the noise. Examples are given for the use of noise (oscillations) to diagnose defects in machines. Analyzed in detail in the book are the principles of the construction and design of the frequency spectrum analyzers used in acoustic spectrometry. Practical questions of spectrum analyzer design are elucidated.

The book is intended for engineering and technical workers engaged in the diagnosis of machines without disassembly and the measurement of nonelectrical quantities using radioelectronic methods.

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CHAPTER THREE

Spectrometry Methods

In spectral-acoustical analysis, the oscillations which arise in a machine are treated as a set of harmonic oscillations with differing amplitudes and frequencies, which reflect the dyanamic state of the mechanism. The dynamic processes transpiring in the machines can be periodic, intermittently repeating, and pulsed ones, which occur at set time intervals. The essence of the method does not change with the nature of the oscillations.

9. Methods of Acoustical Spectrometry

The principle of acoustical spectrometry is clear from Figure 10. It consists of a transducer and a spectrum analyzer. The transducer, which is mounted on the body of the machine, detects all the oscillations arising in the operating machine. It is as if it is listening to the entire mechanism. The "voice" of the components passes freely through the steel and case iron walls from even the most interior locations to the body of the machine. Accompanying any condition in an operating machine is always a set group of symptoms which are reflected in the spectral characteristics of the machine. Each component of the frequency spectrum is characterized by a kinematic pair or another oscillation source. The mechanical oscillations of the machine are detected by the transducer and converted to an electrical current which is proportional to the amplitude of the oscillations, and equal to them in frequency and shape. These signals are fed into the spectrum analyzer. The oscillations are broken down into their individual components in the spectrum analyzer, and their amplitude and frequency are measured.

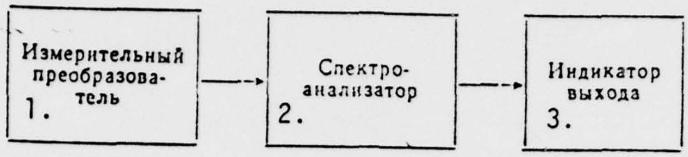


Figure 10. The simplest schematic for an acoustic spectrometry method.
Key: 1. Instrumentation transducer; 2. Spectrum analyzer; 3. Output indicator.

Preliminary calibration is necessary for the diagnosis of the conditions in a specific mechanism: 1) Recording the spectrum of the oscillations of a reference mechanism, from which the relationship of the oscillation parameters (amplitude and frequency) to the state of the machine components is known; 2) Comparing the spectrum of the oscillations of the mechanism being studied with the permissible spectrum of the reference mechanism, which permits the detection of changes which have occurred and the determination of which components are defective.

There are acoustical spectrometer instruments in which two characteristic signal criteria are employed: A spectral characteristic, and a time characteristic.

The time characteristic permits a determination of the duration of one pro- or another which takes placed in the machine. Based on the duration of the impacts, the shocks of the components of one kinematic pair can be distinguished from the shocks of other pairs. One of the diagnosis devices was developed in the Siberian affiliate of the All-Union Scientific Research Institute for agricultural mechanization. The institute named this unit the SAD: system for acoustic diagnosis. In this unit, acoustic spectral analysis is combined with time analysis.

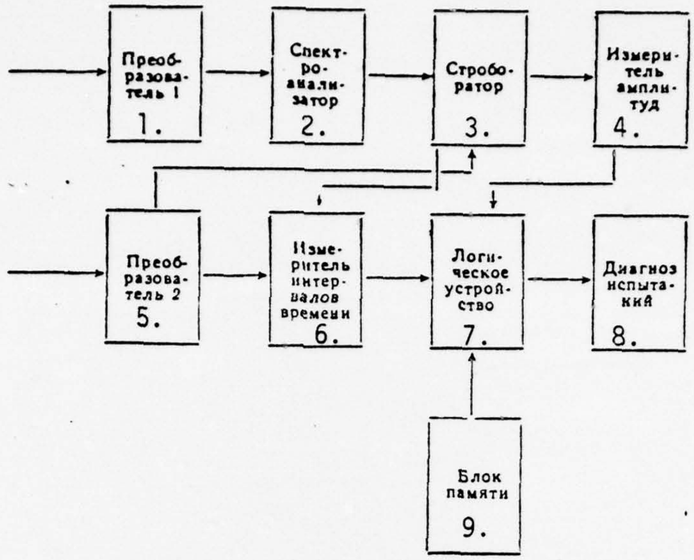


Figure 11. Block diagram of the SAD equipment.

Key: 1. Transducer 1; 2. Spectrum analyzer; 3. Gating unit; 4. Amplitude meter; 5. Transducer 2; 6. Time interval meter; 7. Logic unit; 8. Diagnosis of the tests; 9. Memory block.

In the SAD system there is a "memory" block, in which the recorded signals are stored, where these are a reference standard for the dynamic state of the machine. These signals are compared with the parameters of the signals of the process being studied, and based on the data obtained, the state of the machine is determined automatically.

Shown in Figure 11 is a block diagram of the SAD unit. This unit contains two transducers. Transducer 1 detects all oscillations which are excited in the machine. Transducer 2 can be installed in places where the oscillations being investigated are the most intensive, and is a reference signal transducer with which the operation of all blocks of the system are synchronized.

The electrical signal from transducer 1 is fed to the spectrum analyzer, in which, following spectrum analysis, a range of frequencies is passed through which is characteristic of the oscillations under study. These signals are

fed to the gating unit, from which signals are fed to the amplitude measurement blocks and the time interval measurement blocks. If signals arrive from reference signal transducer 2, the gating circuit passes only the pulses from the pair being investigated to the output, and suppresses all the other pulses. The presence of the gating unit makes it possible to determine which kinematic pairs generate pulses at the moment they arrive (from transducer 2) with respect to a certain reference point.

The time interval measurement block determines the lag or lead of the signals with respect to the reference signal. The diagnosis of mechanism condition is fed out by the logic unit, through which the signals come in from the amplitude measurement block, the time interval block, and the memory block.

10. A Description of the Spectral-Time Diagnostic Method

The author of this book has developed a simpler system, in which spectral and time analysis is also realized. Shown in Figure 12 is a block diagram of this device. It contains a piezoelectric pressure transducer, a spectrum analyzer, a pulse analyzer, and an output indicator.

Figure 12. Block diagram of the spectral-time diagnostics unit.
Key: 1. Instrumentation transducer; 2. Spectrum analyzer; 3. Pulse analyzer; 4. Output indicator.

The pressure transducer is installed on the body of the working machine. The closer the transducer is installed to the point where the process being investigated appears, the less the effect that oscillations produced

spuriously will have. Depicted in Figure 13 is one of the piezoelectric transducer designs. Used as the piezoelectric element is a TsTs-19 lead zirconate-titanate. The mechanical oscillations are converted to an electric current. The electric current of a complex oscillation is broken down into components in the spectrum analyzer. A passband is selected from the resulting spectrogram which corresponds to the calculated frequency for the process being studied. A comparison of the resultant frequency spectrum and the amplitude of the oscillations with the data for the permissible spectrum permits the detection of changes which have occurred in the machine.

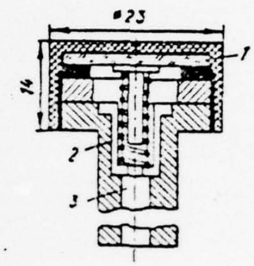


Figure 13. Piezoelectric pressure transducer.
Key: 1. Piezoelectric element; 2. Contact pin; 3. Conductor.

For further investigations, the selected passband is fed from the spectrum analyzer to the pulse analyzer. This device determines the number of pressure pulses per unit time and the intensity of each pulse. Because of this, not only the frequency and the amplitude of the oscillations become known, but also the cycles of the oscillations, their duration, the number of impacts, and their intensity.

The number of pressure pulses per unit time is the first criterion which permits distinguishing the shocks of one pair from the shocks of other pairs. Since the kinematic pairs of the mechanism strike at different times, then one can also determine the time when the knock occurs and with which kinematic pair. A deterioration in the condition of a pair usually leads to an increase in the intensity of the shocks to the components, and thus also to an increase in the amplitude of the acoustic signal. A change in the time of the shocks to the components indicates a lag or lead in a shock.

The pulse analyzer unit contains an amplitude limiter (Figure 14a), a time marker, and a dekatron counter for the number of pulses. The seperation of the number of pulses according to the intensity is realized by a blocking voltage, E_{zap}.

Signals which are greater than the level of the limiting voltage E_{zap} are read out by the pulse counter. The blocking voltage is set manually by means of a voltage divider based on the readings of a microammeter. The level of the blocking voltage characterizes the intensity of the shocks (Figure 14b). A description of the pulse counter unit and time marker are given in (17).

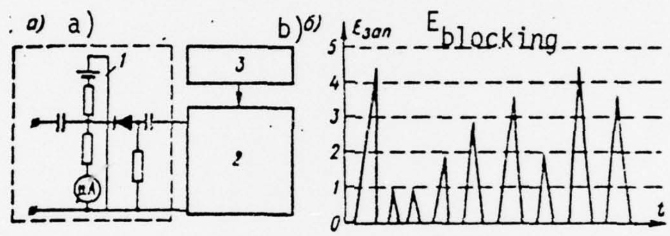


Figure 14. Block diagram of the pulse analyzer (a) and a graph clarifying the action of blocking voltage (b).

Key: 1. Circuit of the amplitude limiter; 2. Counter for the number of pulses; 3. Time marker.

The method treated here makes it possible to obtain data which completely characterizes the process being studied: The frequency of the signal, the intensity, the number of shocks per unit time and the breakdown of the number of shocks with respect to their intensity. The preliminary calibration of the measurement equipment is a necesssary condition for any of the acoustics spectrometry methods.

Magnetic, nondistorting recording of the processes being studied has recently been rapidly introduced. This opens up broad possibilities for accumulating

materials characterizing the state of a mechanism and promotes rapid diagnosis.

11. The Application of Spectral Acoustic Diagnostics

Given in this paragraph are several examples for the application of the spectral-acoustic method of studying and diagnosing various processes and phenomena.

a. Determining the effectiveness of two-phase fuel feed in diesel engines. Diesels with a stringent operational mode are distinguished by high level of combustion noise and vibration. This noise is to a significant extent due to high frequency oscillation components in the noise spectrum. Fuel combustion becomes noisy in a diesel if the maximum rate of increase of pressure with respect to time, dp/dt, reaches 42 - 80 kg/(cm^2 · m · sec).

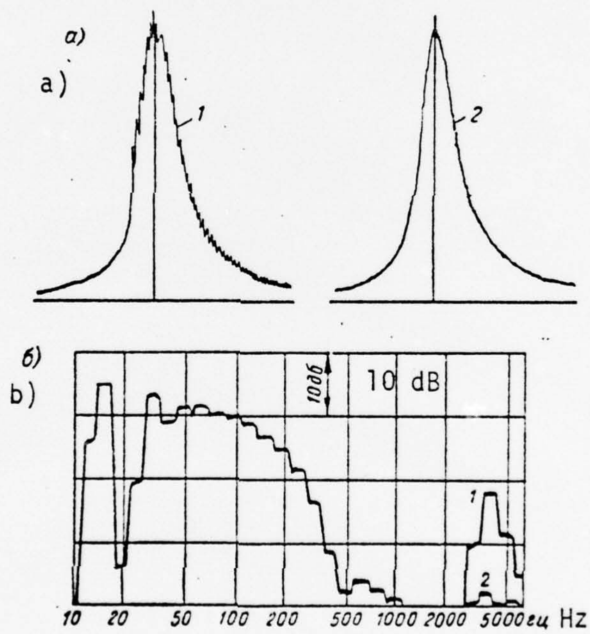


Figure 15. Display traces (a) and the spectra of the pressure in a cylinder of the DK-2 air-injection diesel engine (b).
Key: 1. Standard design; 2. With two-phase fuel injection.

In a free-piston diesel of the DK-2 type, $dp/dt \approx 220 - 230$ kg/(cm^2 · m · sec),

which is significantly above the permissible limit. The high frequency oscillations of *dp/dt* can be clearly seen on the display trace for the combustion curve and the pressure spectrum (Figures 15a and b). Two-phase fuel injection is used in the DK-2 diesel to reduce the severity and noise of the combustion process. The maximum rate of pressure increase, *dp/dt*, drops down to 50 - 77 kg/($cm^2 \cdot m \cdot sec$), while the high frequency pressure oscillations disappear. This can be seen from the display trace (Figure 15b) and from the noise spectrum. The noise level of the diesel decreases by 8 dB. At the same time, magnitude of the maximum pressure does not change with two-phase fuel injection. The small extent of the noise spectrum and the low level of high frequency pressure spectrum components characterizes the effectiveness of two-phase fuel injection and the refinement of the operational process of the diesel. This process can be revealed by means of a pressure transducer and a spectrum analyzer.

b. Diagnosing the play in the spindles of machine tools. Presented in the literature (21) is a diagnostic procedure for the play in the spindles of machine tools, mounted on roller bearings. The interaction of the bearing parts during the rotation of the spindle creates a complex oscillation, in which are reflected all the factors causing play in the spindle.

The diagnosis is made by the acoustic spectrometry method. The pulsations in the spindle were recorded by means of transducers, and the resulting oscillations were broken down into components by a spectrum analyzer, i.e. the spectral analysis of the oscillations was realized. It was established that the primary sources of spindle play were the eccentricity in the opening of the inner ring of the bearing with respect to the roller race and with respect to the measurement surface, as well as inadequate resilience and nonuniformity of the roller races.

To evaluate the quality of machine tool spindle assembly, it is necessary to individually determine the magnitude of the pulsations (H_{avg} is the amplitude) of the spindle and the pulsation (H) of the axis of rotation of the spindle.

Shown in Figure 16 are curves for the pulsations of a lathe spindle. These curves are broken down into a Fourier series of three components. The first component takes the form of the sum of all harmonics with a frequency lower than the rotational frequency of the spindle, ω, i.e. $\omega < \omega_H$. The peak-to-peak value, H_1, is the quantitative characteristic of this component. The peak-to-peak value, H_1, of the frequency components, ω, indicates the error in the set of rolling parts due to the roughness of the surface of the component and the effect on the precision of spindle rotation. The second component of the oscillation takes the form of a harmonic at a frequency of $\omega = \omega_H$. The peak-to-peak value H_2 yields its quantitative characteristic. If the peak-to-peak value H_2 comprises 80 - 90% of the spindle pulsations, then the precision in the machining of products on milling and gear cutting machines will be significantly reduced.

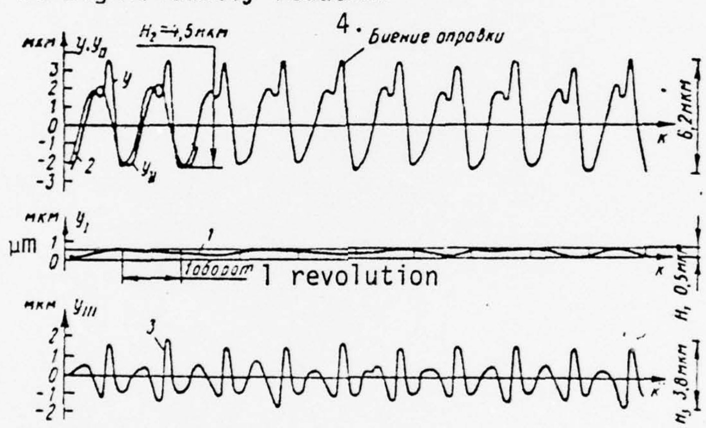


Figure 16. Curves of machine tool spindle pulsation.

Key: 1, 2, and 3. The first, second, and third components of spindle pulsation. 4. Mandrel pulsation.

The third component of the oscillations take the form of the sum of all frequency harmonics which are higher than the spindle rotation frequency, i.e. $\omega > \omega_H$. This region of oscillation frequencies is due to the shift of the spindle axis of rotation caused by the rotation of the inner ring of the bearing. The peak-to-peak value H_3 yields the quantitative characteristics of the influences of the error in the shape of the roller races on the precision of spindle rotation.

Shown in Figure 17 is a more detailed spectrum analysis of machine tool pulsation. The authors of the paper [21] evaluate the results obtained in the following manner. The eccentricity (c) of the surface being measured with respect to the spindle axis of rotation is not large: $c_{10} = 2.3\ \mu m$ when $H_{10} = 4.5\ \mu m$. The quality of the set of rollers is high: $c_1 - c_{10} < 0.1\ \mu m$; $H_1 = 0.5\ \mu m$. The error in the shape of the roller races is considerable, $H_3 = 3.8\ \mu m$. The ellipticity is sharply pronounced ($c_{20} = 0.9\ \mu m$), as is the trihedral factor ($c_{30} = 0.7\ \mu m$), while the overall level of the remaining frequency components of this region is less than 0.07 µm.

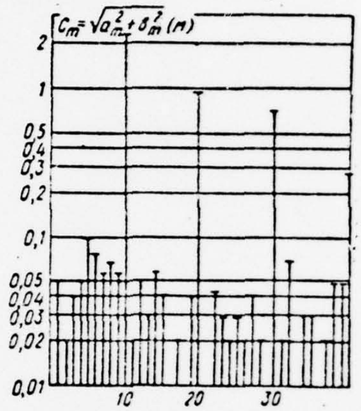


Figure 17. Spectrum of machine tool spindle pulsation
m is the number of the harmonic

Based on the resulting spectrogram, there is complete justification for assuming that a high precision bearing with a small degree of waviness of the roller races was installed in this spindle assembly. However, this bearing was mounted on a spindle which was sharply out-of-round. A subsequent check confirmed these suppositions. If the measurements are made manually, it is impossible to take into account the influences of dynamic factors which arise with the continuous rotation of the spindle. Manual measurements of the spindle pulsations are laborious and require extensive computations to process the data obtained. The spectral method was employed for the analysis of the pulsations of spindles mounted on roller bearings in lathes. The instruments for measuring the pulsation magnitudes of the spindle should be calibrated.

C. Diagnosing the pulsations in internal combustion engines. All dynamic processes which occur in the mechanism of internal combustion engines are accompanied by oscillations. The oscillations in an internal combustion engine are created by the combustion processes, the crank and connecting rod mechanism, etc. The shocks of the pistons, moving parts of the fuel nozzles, and the shocks of the valves when lifting and seating occur in a set sequence and at set points in time. All of these oscillations are reflected in the frequency spectrogram of the engine when using the spectral method. The natural oscillation frequencies of the colliding and main components are determined by a computational approach taking their dimensions, methods of fastening, etc., into account. Based on the resulting data, one can establish the relationship between the frequency components of the spectrum and the state of the mechanism. Thus, for example, by knowing the motions frequency of the primary engine mechanisms, a kinematic pair can be identified based on the frequency of the shocks and their duration in different joints of the mechanism. The travel of a piston in an engine cylinder (Figure 18) can serve as an example of the process indicated here. When the piston of the engine passes top (or bottom) dead center, the horizontal component F of the connecting rod changes direction; the shift of the piston is accompanied by a shock. The greater the gap between the piston and the cylinder wall, the stronger the shock is. With an increase in the gap, the delay in the shock increases, since the piston requires more time to shift over. The repitition rate of the shocks (in the cylinder) of the piston group differs from the frequency of the shocks of a geared pair, and for this reason it is not difficult to decipher which kinematic couplings are the sources of the oscillations pulses.

D. The determination of the operational qualities of geared transmissions and mechanisms. In recent years, acoustical spectrometry has been widely used to determine the operational qualities of geared transmissions and mechanisms. For this purpose, a microphone, which is connected to a frequency spectrum analyzer, is set up in the immediate vicinity of the operating

gears. The fabrication quality of the individual engaging components is evaluated based on the spectrum of the acoustic oscillations, and the magnitudes of the dynamic forces arising during the operation of the gears is determined. Experimental investigations have shown that a spectral component is determined by the engaging frequency, the oscillations of the gear bodies, and the special features of the dynamic loading, etc.

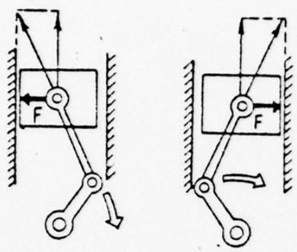


Figure 18. Shift in piston travel in an engine cylinder.

The German specialist, Zink, has isolated four groups of spectra based on numerous analyses of the frequency spectra of various geared transmissions. Included in the first group are the frequency spectra produced by spur-gear wheels where there are errors in the primary pitch and by helical gears where errors are present in the slope angle of the teeth. The spectrum of such a group is shown in Figure 19a. Included in the second group are the frequency spectra caused by pulses at a frequency equal to the frequency at which the gears engage. The spectrum of this group is shown in Figure 19b. The third group includes the frequency spectrum caused by both the frequency of the engaging and the periodic disruption of contact between the faces of the teeth (Figure 19c). The fourth group contains the spectrum, the frequency of which is determined by the operation of a reducer gear (Figure 19d).

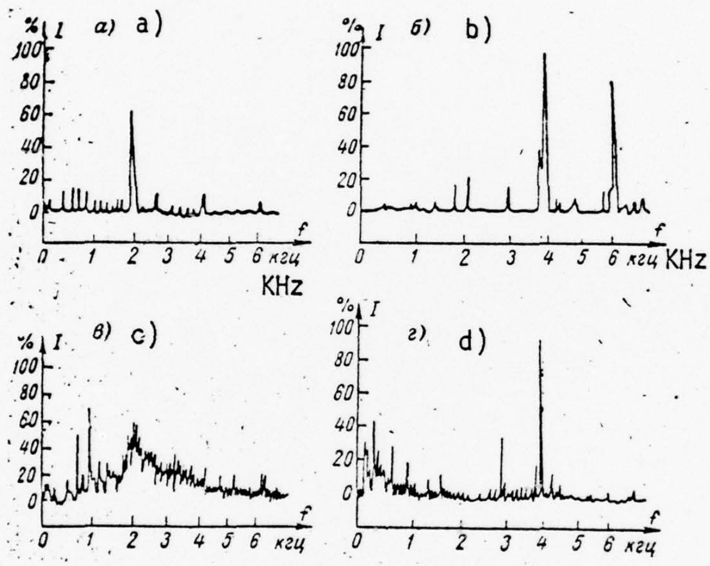


Figure 19. The noise spectra of various geared transmissions. I: Sound intensity.

CHAPTER SEVEN

Spectrum Analyzer Design

The circuit and structural solution for a frequency spectrum analyzer is determined by its function. Various components are used in the construction of the analyzer depending on this purpose. Given in this chapter are specific circuits and designs of various infrasound and audio frequency analyzers. Analyzers with a selective system using RC, mechanical and crystal filters are described, and their interrelationships with other circuit components is shown.

34. Audio and Infrasound Analyzers

The infrasound frequency analyzer. The infrasound analyzer described here is intended for measuring voltage components in a frequency range from 2 to 1000 Hz. The measurement is broken down by subranges. The analyzer operates in a sequential analysis mode. Used as the selective system is a selective amplifier with a twin T-section bridge. The minimum input sinusoidal voltage which yields full scale deflection of the meter is 0.5 volts. The analyzer is equipped with a voltage divider which makes it possible to study voltages of up to 50 volts.

Shown in Figure 55a is the basic schematic of the analyzer. It consists of a preamplifier, a selective stage, a voltmeter and a regulated rectifier (see figure 55b). The voltage being studied is fed through the voltage

divider to the input of the preamplifier. The divider has division factors of 1, 3, 10, 30 and 100.

Following preamplification (k = 5), the voltage is fed through the grid of tube L2a. The voltage taken from the plate of this tube is fed through the grid of cathode follower tube L3. Connected to the cathode circuit of this tube is the input of the T-section bridge. The cathode follower eliminates the shunting of the plate load of the amplifier. The bridge output is connected to the grid of tube L2b, which is connected in series with tube L2a. Such a circuit prevents the bridge shunting the plate load of the amplifier stage. The bridge is tuned to the frequency of the voltage being analyzed by means of three variable resistors, R1, R2, and R3. Connected in series with these resistors are six resistors r1 and r2, which make it possible to obtain the requisite overlap in the range being adjusted. Switching in a frequency subrange in the analyzer is accomplished by switching capacitors of the twin T-section bridge.

For precise balancing of this bridge, it is necessary that its "vertical" impedance be equal to the "horizontal" impedance . The passband of the filter is adjusted by varying the gain of tube L2b. These variations are realized by a divider inserted in the feedback circuit. The voltage from the cathode follower is fed to the volt meter from the rectifier bridge. The voltage from the output of the amplifier is fed to the output terminals for a connection to an oscilloscope. The circuit is powered from a rectifier with electronic voltage regulation, designed around tubes L5, L6, and L7.

The analysis of the voltage being studied is accomplished in the following fashion. The T-section bridge is tuned on the frequency scale using resistors R1, R2, and R3 for maximum volt meter deflection. The desired frequency is read from the frequency scale for this voltage. All manual controls are located on the exterior panel of the instrument: for the voltage divider, the range switch, etc. The frequency scale pointer is connected to the rheostats. The rheostats are wound on five trapezoidal

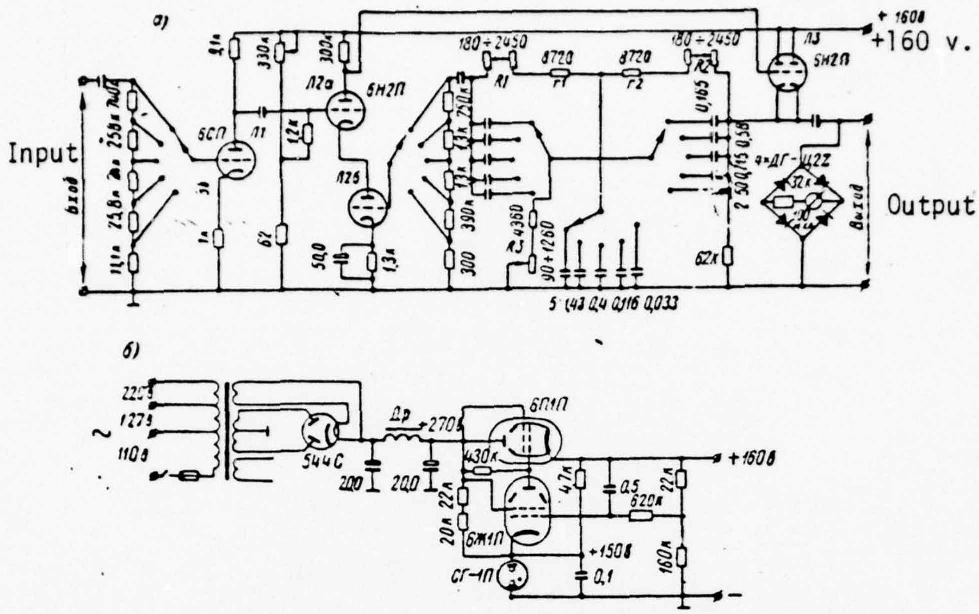


Figure 55. Basic schematic of an infrasound frequency analyzer, in which a twin T bridge is used as the selective system.

frames, the shape of which permits obtaining a logarithmic scale. There is a corrector for adjusting the scale.

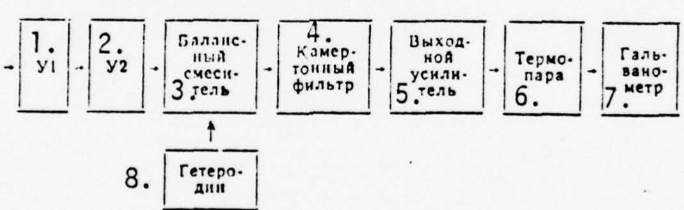


Figure 56. Block diagram of a low frequency analyzer.

Key: 1. U1, amplifier 1; 2. U2, amplifier 2; 3. Balanced mixer; 4. Tuning fork mechanical filter; 5. Output amplifier; 6. Thermocouple; 7. Galvanometer; 8. Heterodyne.

A high sensitivity low frequency analyzer. The analyzer being considered here is intended for the determination of voltage components with frequencies of 1 - 400 Hz. The analyzer works on a heterodyne principle

with an intermediate frequency of 440 Hz. The passband is $\Delta f = 0.5 - 1$ Hz. Tuning to the frequency being studied is accomplished by varying the heterodyne frequency. A special feature of this circuit is the use of a tuning fork mechanical filter with an extremely narrow passband, because of which one can determine the spectrum of extremely low frequency. The measurements are made in four ranges: 1) 1 - 70 Hz; 2) 60 - 170 Hz; 3) 160 - 300 Hz; 4) 290 - 400 Hz. A block diagram of the analyzer is shown in Figure 56. The analyzer contains two input amplifiers, U1, and U2, a balanced mixer BS, a heterodyne stage Get, a tuning fork mechanical filter KF, and an output amplifier VU, and a voltage indicator (Figure 57). When measuring strong signals, amplifier U_2 is used, and for weaker signals, the two amplifiers are used simultaneously. The overall gain of U1 and U2 is $k \approx 10^5$. These amplifiers are designed around 6zh8 tubes; a considerable gain is achieved because of the light plate loading. The stage using the 6n15P tubes is a cathode follower and serves for matching the mixer.

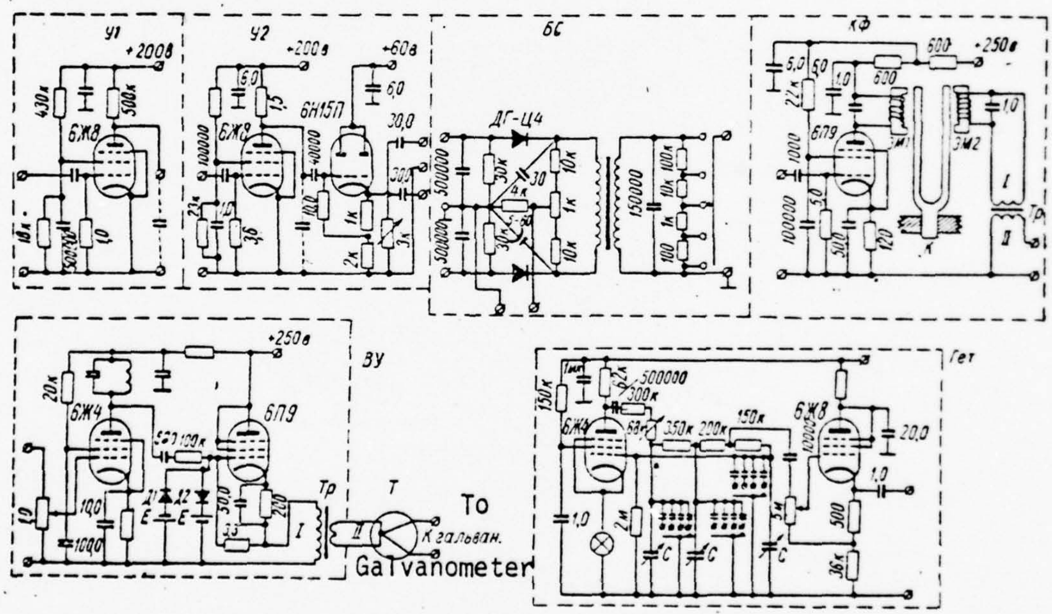


Figure 57. Basic circuit of a high sensitivity, low frequency, harmonic analyzer.

The circuit of the balanced mixer, BS, is designed around crystal diodes. The mixer is balanced by variable resistor R and variable capacitor C. The secondary winding of the transformer is tuned to resonance at the intermediate frequency of 440 Hz.

In the tuning fork mechanical filter circuit, KF, by adjusting the spacing between the electromagnets EM1 and EM2, the passband of the filter can be changed within small limits. The tuning fork is tuned to 400 Hz. The gain of the KF amplifier with the tuning fork filter is low, usually k = 2 - 10 depending on the passband.

The heterodyne stage is the usual single tube RC oscillator. It has four ranges: 1) 440 - 510 Hz; 2) 500 - 610 Hz; 3) 600 - 740 Hz; 4) 730 - 840 Hz. The heterodyne frequency is tuned precisely to 440 Hz by means of variable resistor R2.

The output amplifier circuits, U3, with the meter, is depicted in the same Figure 57. The plate load of the first stage is tuned to 440 Hz. A diode limiter, consisting of diodes D1, D2, and a resistor, is inserted between the stages. Used as a voltage indicator in the second stage is a galvanometer with a thermocouple. Their time constant is 20 seconds.

The circuits of all the assemblies are carefully shielded, because of which, hum and feedback from the mains has practically be eliminated; in this case, a stable gain of $k \approx 10^5$ is achieved.

A simple low and infralow frequency analyzer. The spectrum analyzer considered here is intended for the spectral analysis of electrical oscillations in a frequency range of 1 - 500 Hz. The analysis is made using the heterodyne method. A special feature of the circuit is the use of a twin P bridge as the selective system. A block diagram of the spectrum analyzer is shown in Figure 58. The circuit contains two channels. The input signal is fed through the wideband amplifier, VU, with a high input impedance. When

analyzing frequencies of 1 - 100 Hz, the first channel operates, which contains a selective transistorized amplifier designed around a RC network (FNCh1) with a cutoff frequency of f ≈ 120 KHz. The output of the amplifier is connected to the mixer which is designed in a ring configuration using crystal diodes.

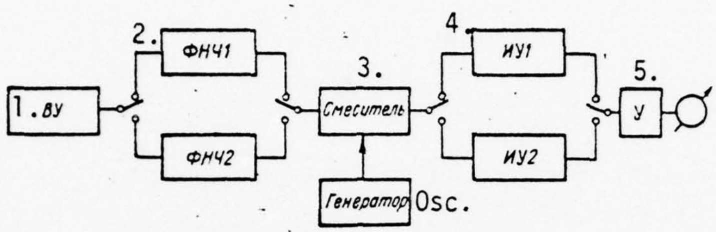
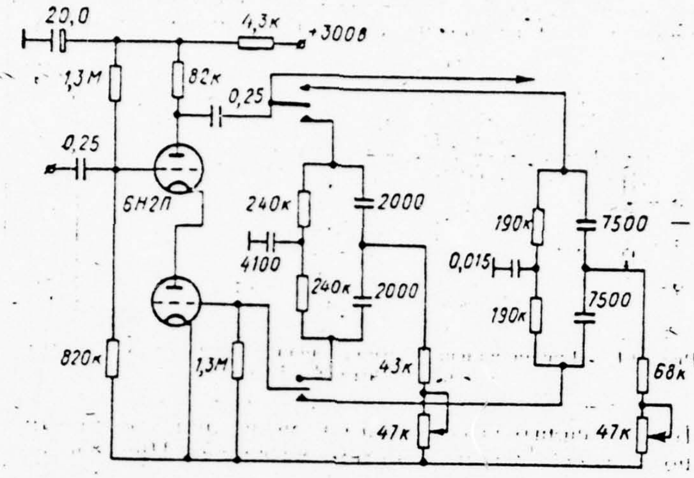


Figure 58. Block diagram of a low and infralow frequency spectrum analyzer. Key: 1. VU, wideband input amplifier; 2. FNCh1, low frequency selective amplifier 1; 3. Mixer; 4. IU1, selective amplifier; 5. U, output amplifier.

Selective amplifier IU1 is designed around RC networks and is tuned to a frequency of 120 Hz and has a passband of about 0.3 Hz. A second channel is inserted for the 100 - 500 Hz analyzer. The FN2 amplifier is also a RC selective transitorized amplifier. Amplifier IU2 is tuned to a frequency of f ≈ 510 Hz and has a passband of f ≈ 2 Hz. The circuit for the frequency selective stage of IU1 and IU2 is shown in Figure 59. The filament power for the tubes in this amplifier is delivered at reduced voltage. With a proper matching of the resistors and capacitors, the circuit is distinguished by good stability. The final amplifier and indicator is a standard V6-4 instrument.

A low frequency spectrum analyzer using semiconductors. The analyzer described here is distinguished here by a significantly simplified construction and is designed for joint operation with any audio generator and vaccum tube voltmeter. The analyzer is intended for analyzing a frequency spectrum in a range of from 5 - 1000 Hz. The precision in the analysis of oscillation components is 2 Hz. The sensitivity of the analyzer depends to a large extent on the sensitivity of the vaccum tube voltmeter. For a sinusoidal voltage of 0.02 volts at the input, there will be 0.5 volts at the

analyzer output. The analyzer is powered from dry batteries at 20 volts.



The circuit of the frequency selective stage.

Figure 59.

A tuning fork mechanical filter, which has a narrow passband, is used as the element which breaks down the complex oscillation into its components. The analyzer is designed on a heterodyne principle, according to which the components of the complex oscillation being studied are converted to another frequency.

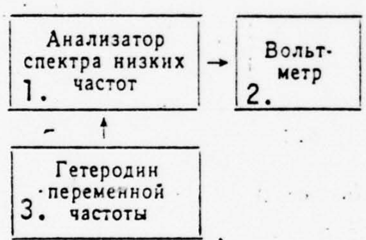


Figure 60. Block diagram of a low frequency spectrum analyzer using semiconductors.
Key: 1. Low frequency spectrum analyzer; 2. Voltmeter; 3. Variable frequency heterodyne stage.

Shown in Figure 60 is a block diagram of the low frequency analyzer; the basic circuit of the analyzer is shown in Figure 61. The voltage being studied is fed through the input to the two-stage amplifier designed around transistors. The output of the amplifier is connected to the mixer designed in a balanced ring configuration using diodes. The use of a mixer of this type makes it possible to obtain a minimum number of combination tones. The unknown frequency is converted to the intermediate frequency in the heterodyne mixer stage.

The filter consists of an electromagnetic system and a tuning fork. The tuning

fork is fabricated from elinvar. Used as the electromagnet system are standard electromagnets from the telephone receivers manufactured by the "Krasnaya Zarya" plant. The gap between the tuning fork and the electromagnet is set at 0.1 mm.

We shall treat the operation of the analyzer using a specific exampl . Let a distorted current curve containing components at frequencies of 50, 100, 200, and 300 Hz be investigated. The intermediate frequency of the analyzer, and consequently, the frequency of the filter is 5,600 Hz. The determination of the components frequencies is made based on the heterodyne frequency. To find the components of the 50 Hz current, the heterodyne frequency is varied until reaching 5,550 Hz. Two sidebands are produced in the ring modulator: 5,550 Hz + 50 Hz = 5,600 Hz, and 5,550 Hz - 50 Hz = 5,500 Hz. The 5,600 Hz frequency is passed by the tuning fork filter, amplified, and its amplitude measured by the vacuum tube voltmeter. The voltage at a frequency of 100 Hz which is being studied, is measured when the oscillator frequency is 5,500 Hz, etc.

The tuning of the analyzer is begun with a check of the correspondence of the frequency between the oscillator and the resonant frequency of the filter. For this purpose, potentiometer P1 disrupts the balance of the modulator and sets the oscillator frequency so that the voltage at the vacuum tube voltmeter is a maximum. The frequency of the oscillator should be 5,600 Hz. After this operation, the balance is restored in the modulator. For this, potentiometers P1 and P2 are set so that a minimum voltmeter reading is obtained, after which the analyzer is ready for operation.

A precision infralow and low frequency spectrum analyzer. Described in the following is a precision spectrum analyzer for the two-550 Hz range with a resolving power of 0.3 Hz: a sequential type analyzer with single heterodyning. A block diagram of the analyzer is shown in Figure 62. The circuit is constructed using transistors. Bridge type, narrowband crystal filters are used in the circuit, which make it possible to obtain a passband of 0.1 Hz.

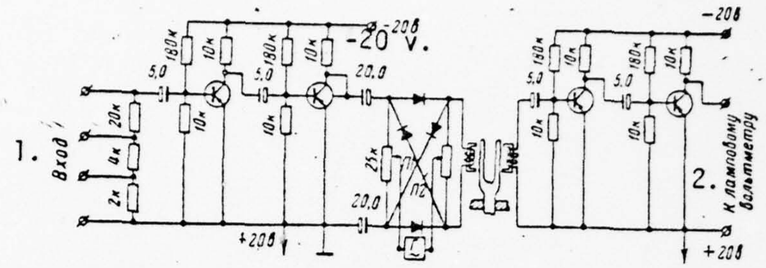


Figure 61. Basic circuit of an analyzer with a tuning fork mechanical filter.

Key: 1. Input; 2. To the vacuum tube voltmeter.

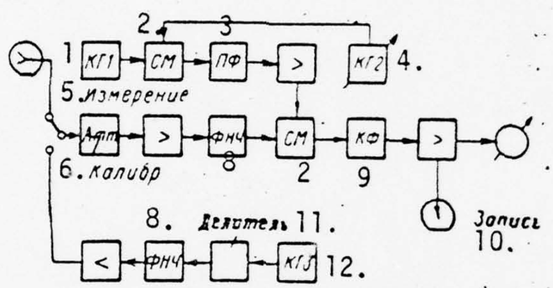


Figure 62. Block diagram of a precision infralow and low frequency spectrum analyzer.

Key: 1. KG1, oscillator; 2. SM mixer; 3. PF, bandpass filter; 4. KG2; 5. Measure; 6. Calibrate; 7. Ammeter; 8. FNCh, selective amplifier; 9. KF crystal filter; 10. Record; 11. Divider; 12. KG3.

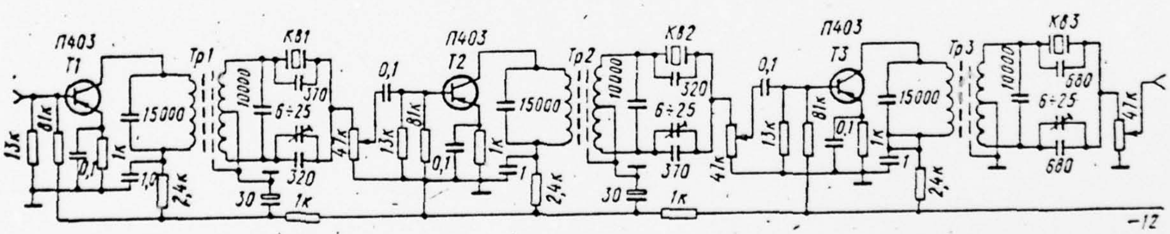


Figure 63. Basic schematic of the crystal filter.

The spectrum analyzer has an intermediate frequency of f_{if} = 10 Hz. The circuit of the crystal filter is shown in Figure 63.

The heterodyne circuitry (Figure 64) consists of two crystal oscillators, one of which is tuned by a variable capacitor. The frequency of the crystal oscillators is $f > 1$ Mhz and $f_2 = (1.01 \pm 0.0005)$ Mhz.

The crystal oscillator frequencies are subtracted in the mixer, at the output of which a difference passband is obtained. The crystal oscillators operate at ultralow subharmonics of the crystal. The output indicator is a metering instrument and a N-110 auto-recording voltmeter. The heterodyne tuning is mechanical, and synchronized with the motion of the auto recorder chart.

35. Audio Frequency Spectrum Analyzers

We shall consider one of the designs of a spectrum analyzer in which the selective systems consist of a set of RC filters.

An analyzer for studying the noise spectrum in a frequency range of 30 - 11,000 Hz. The entire range is broken down into 25 bands with a passband of 1/3 octave each. The geometric mean frequencies (in Hz) are as follows after passing through the filters: 40, 50, 64, 80, 100, 125, 160, 200, 250, 320, 400, 500, 640, 800, 1,000, 1,250, 1,600, 2,000, 2,500, 3,200, 4,000, 5,000, 6,400, 8,000, and 10,000. Two RC frequency selective amplifiers are connected in series to increase the analyzer selectivity. The design principle of such an instrument has been treated in § 20.

The basic circuit of an ASh-2-LIOT type noise spectrum analyzer is shown in Figure 65. The circuit consists of two RC frequency selective amplifiers and an output stage designed around two triodes. The circuitry of the frequency selective amplifiers is designed around two series connected triodes, where the output of a T-section bridge is connected to the grid of the lower tube.

During measurements, the signal is fed to the input of the grid of the upper tube of the first stage. The voltage from the plate of the tube is fed to the grid of the cathode follower. The narrow band frequency is fed from the cathode follower through the T-section bridge to the grid of the lower tube, L2a. The signal is then further amplified and fed to a cathode follower.

The signal from the cathode follower goes to a rectifier bridge, built up from semiconductor diodes. A microammeter, graduated in decibels, is inserted in the bridge diagonal. An auto recorder for recording the noise components can be connected to the output of the cathode follower. The average sensitivity of the analyzer when a sinusoidal voltage of 30 mv is fed to its input is such that there is full-scale deflection of the meter.

All the requisite passbands are realized by means of R and C combinations. The entire band is frequently broken down into five subranges, which change when the capacitors are switched. Within each subrange, the transition from one fixed frequency to another is realized by changing the resistance.

Used in the block of filters are two standard four-stator switches. The filters are switched by one control using a special mechanism. This mechanism consists of three gears: The driving gear on the axis of the switch for R, and an idler and driven gear on the axis of the switch for C.

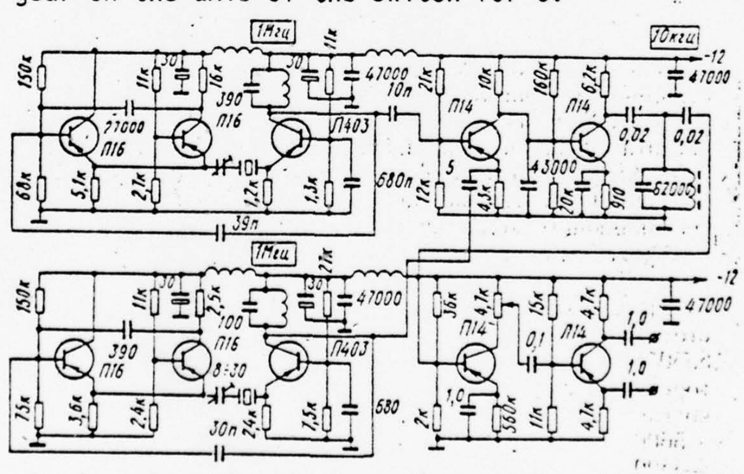


Figure 64. Basic schematic of the analyzer heterodyne unit.

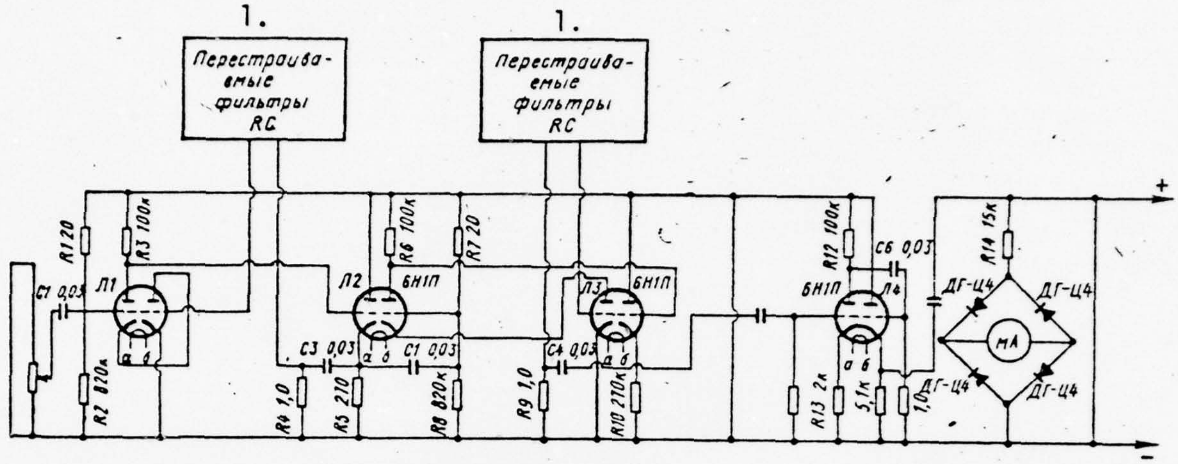


Figure 65. Basic circuit of the noise spectrum analyzer.
Key: 1. Tunable RC filters.

A simple harmonic analyzer. The instrument described here is intended for the analysis of the audio frequency spectrum in a range from 100 to 15,000 Hz. The analyzer sensitivity for sinusoidal signals makes it possible to measure voltages from 50 mv to 50 v. The analysis precision for complex harmonics is 20 Hz. The harmonic analyzer works on a heterodyne principle. The analyzer is powered from the main at 90, 100, 110, or 130 volts.

Shown in Figure 66 is the basic schematic of the analyzer. The voltage being studied is fed to a phase inverter stage, which is a preamplifier, and feeds two equal out-of-phase voltages to the balanced modulator. This stage makes it possible to attain a better frequency response than when using a transformer. The phase inverter stage is designed around a 6N72. The signal being analyzed is combined with the balanced modulator with a set heterodyne frequency. In this case, the sum and difference of these frequencies appear, the so-called sidebands.

The carrier frequency is suppressed in the balance modulator. When the heterodyne frequency is chosen so that it yields a resultant frequency (sideband) with the complex signal component, where this resultant is equal to the frequency

of the crystal filter, then the filter passes it through. The crystal filter stage in this circuit consists of a 6N9 tube (the left triode), the plate load of which is Ra = 2 Kohms, and a crystal, inserted as an isolating capacitor. Increasing the plate resistance of this stage leads to a broadening of the passband of the filter, something which is not desirable. The resonant frequency of the crystal is 50,000 Hz, and the passband is ± 20 Hz.

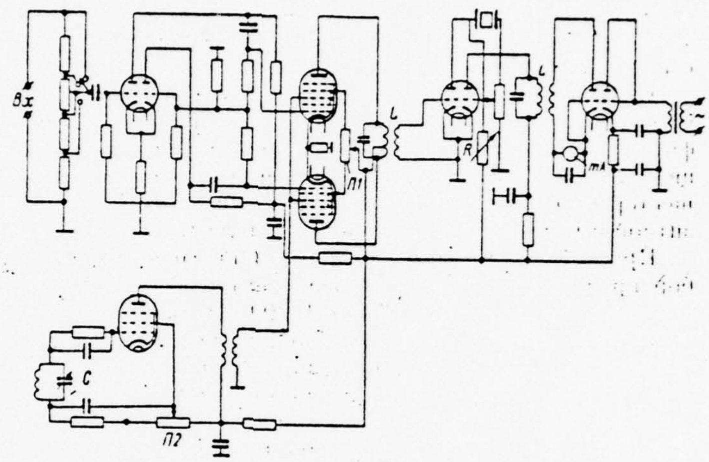


Figure 66. Basic schematic of a simple harmonic analyzer..

The voltage is amplified by the right triode section of the 6H9 tube following the crystal, and is rectified by the diode formed by the 6N8 tube. The level of the rectified current is proportional to the amplitude of the complex current component being studied. The right triode section of the 6N8 tube is inserted as a diode to rectify the mains voltage. The heterodyne works through the 6Zh7 tube in a cathode coupled configuration, which is distinguished by high stability. A slight fine tuning of the frequency is realized by changing the voltage to the screen grid by means of potentiometer P2.

We shall consider the operation of the analyzer using a specific example. Let a distorted current waveform, containing components at frequencies of 400, 800, 1,200 Hz be investigated. The intermediate frequency, and consequently, the filter frequency is 50,000 Hz. The heterodyne frequency is varied by the variable capacitor of the resonant circuit from 35,000 to 50,000 Hz.

To determine the 400 Hz component, the variable capacitor for the heterodyne stage is rotated until a heterodyne frequency of 49,600 Hz is obtained. Two sidebands are produced in the balanced modulator: 49,600 Hz + 400 Hz = 50,000 Hz and 49,600 Hz - 400 Hz = 49,200 Hz. The 50,000 Hz frequency is passed by a filter, amplified, and the amplitude of the signal measured by a diode voltmeter. The frequency of the 800 Hz signal is measured when the heterodyne frequency is 49,200 Hz, etc. Thus, the frequency of the components of a complex oscillation is determined based on the heterodyne frequency. The amplitude of the current component is defined as the maximum deflection of the pointer of the meter, which is graduated in volts. As can be seen from the schematic, the harmonic analyzer is a simple device. The resonant frequency crystal (50,000 Hz) can be replaced by a different frequency crystal, based on the magnitude of the permissible accuracy of the frequency determined for the signal being studied. The higher the resonant frequency of the crystal is, the wider the passband of the filter and the less precisely the frequency of the signal being studied is determined.

In selecting a crystal, one can work from the fact that for each 10,000 Hz of the resonant frequency of the crystal, there should be 10 Hz of passband. Thus, for a crystal with a resonant frequency of 200,000 Hz, the passband is approximately 200 Hz. For the purposes of keeping the dimensions of the coil L small, it is best that it be wound on the compressed iron core. The coils of the heterodyne circuit should not be made on compressed iron cores so as to increase the stability. The construction of the harmonic analyzer depends on the type of vernier used for the capacitor C.

In its tuning simplicity, the harmonic analyzer is similiar to uncomplicated radio receivers. Required to calibrated is an audio oscillator from 50 to 15,000 Hz and a vaccum tube voltmeter. The analyzer should be aligned in the following fashion. The knob of potentiometer P1 is positioned so that the voltage at the screen grids is different. This disrupts the balance in the modulator, because of which a carrier frequency appears which passes through the remaining stages. Once convinced that the heterodyne stage is operating

and capacitor C is completely closed, one selects the inductance so that the milliammeter shows the maximum deflection. This matches the heterodyne frequency to the resonant frequency of the crystal. When these frequencies are equal, the maximum voltage is achieved at the filter output. Then potentiometer P1 is set so that the milliammeter shows minimum readings. The balance in the modulator is restored. With a small change in the capacitance C, the instrument readings should fall off to 0.

The L circuits are tuned to resonance for the intermediate frequency until a maximum deflection of the milliammeter is obtained. When measuring the frequency being studied, the rotor of capacitor C is set in such a position that the readings of a milliammeter are also a maximum. This position is registered on the frequency scale and corresponds to the frequency of the audio oscillator.

Increasing R extends the filter bandpass and increases its gain. A scale graduated analyzer is prepared for operation as follows. The analyzer is plugged into the mains and the "frequency" scale is set to "0" by heterodyne tuning potentiometer P2, and a maximum deflection of the meter A is achieved. Then the balance of the modulator is checked using potentiometer P1 and minimum readings on the meter indicated are obtained, i.e. the carrier frequency is attenuated after which the analyzer is ready for operation.

A dual frequency conversion analyzer. Dual frequency conversion is realized in the SG-3 audio frequency analyzer. A block diagram of the analyzer is shown in Figure 67. The input signal is fed to a voltage divider, and from it to emitter follower 1. This stage matches the high impedance input of the analyzer to the low impedance input of the low pass filter 2. The signal from the filter is fed to the first converter 3, in which the signal frequency is converted by means of heterodyne stage 12 to an intermediate frequency of 110 KHz. The heterodyne frequency can change within limits of from 90 to 110 KHz. The voltage is fed from the output of the converter to the input of a tuned amplifier, which is tuned to 110 KHz. This amplifier is the first intermediate frequency amplifier 4. It provides for the attenuation of the

image frequency $f_i = f_{if} + 2f_{if}$ by 20 dB and more.

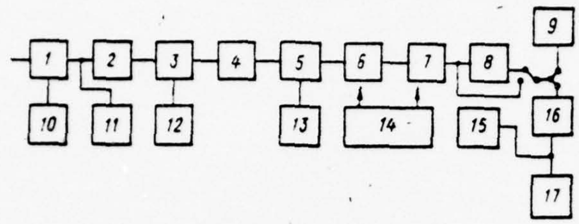


Figure 67. Block diagram of an analyzer with dual frequency conversion.

The second converter 5 by mixing the 118 KHz frequency of the second heterodyne stage 13, forms the second intermediate frequency of 8 KHz. The signals of the second intermediate frequency are fed to the input at filter 6, which is tuned to 8 KHz. The filter passband is 200 Hz. The signals are fed from the output of the amplifier to the input unit 7 of the voltmeter. Here it is limited to a voltage of 200 μv, which corresponds to the voltmeter sensitivity by means of a voltage divider.

For analyzer operation with a more narrow band of frequency, there is quartz filter 8 with a passband of 6 Hz, which is inserted between the voltmeter input unit 7 and the voltmeter 9. The signals of the frequency spectra components can be measured by the voltmeter, recorded on an oscillascope 15, or on auto-recorder 17. There is a calibrator 10 and a signal input level meter 11 in the analyzer. Only one set frequency for the tuning of the first heterodyne 12 corresponds to each frequency of the range being investigated. This makes it possible to graduate the analyzer directly in the frequencies of the range being investigated according to the tuning of the heterodyne stage. The circuitry is powered from block 14.

36. Industrial Types of Audio and Infrasound Analyzers.

A series of spectrum analyzers with extremely wide frequency ranges is produced in our country. Simultaneously with this, many organization fabricate spectrum analyzers to solve special problems, including those of acoustical spectrometry.

Given below (Table 3) are the technical data for spectrum analyzers produced by industry.

TABLE 3

Frequency Spectrum Analyzers, Manufactured in the USSR

Designation and Brand of the Instrument	Analysis Method	Frequency Range, Hz	Width of the Analysis Passband	Type of Indicator
AS-3 spectrum analyzer	sequential	20-60,000	a constant relative passband width of 1.5, 3 and 10%	meter
S53 harmonic analyzer	sequential	20-20,000	constant passband of 6-150 Hz	meter
AN2 tuning fork mechanical filter analyzer	sequential	5-100	constant passband of 112 Hz	autorecorder
ASChKh-1 (SKch43) spectrum analyzer	sequential	20-500 60-5000 400-20,000 5-100	constant passbands of 12, 60, 100, and 400 Hz	CRT
S32 audio frequency spectrometry	simultaneous	50-20,000	constant relative passband width in 1/3 octaves	CRT, meter, autorecorder
PF1 half-octave filter	sequential	50-10,000	constant relative passband width in full octaves	filters without indicators

37. A Built-Up Frequency Spectrum Analyzer

There are often cases in laboratory practice where a frequency spectrum analyer is built-up from existing, ready made instruments: an audio generator, vacuum tube voltmeter, and selective amplifier. Such a set up is easy to put together

and is excessible to many laboratories. Shown in Figure 68 is a structural schematic of one of these set-ups for frequency spectrum analysis based on the heterodyne method. Used for this set-up is a special attachment, containing a mixer and a selective amplifier, which permits analyzing frequency spectra from 10 Hz up to 8.5 KHz.

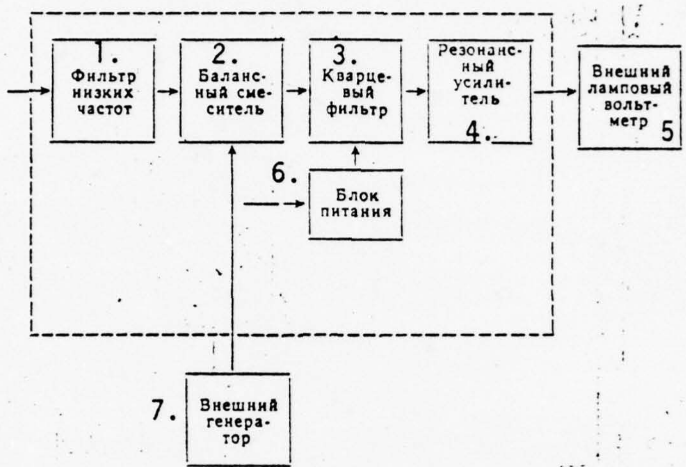


Figure 68. Structural schematic of a built-up spectrum analyzer.
Key: 1. Low pass filter; 2. Balanced mixer; 3. Crystal filter; 4. Tuned amplifier; 5. External vacuum tube voltmeter; 6. Power supply block; 7. External oscillator.

The basic circuit of the analyzer is shown in Figure 69. The signal being studied is fed through the voltage divider to a cathode follower, which is matched to the input of the preliminary filter. The filter is intended for preventing the oscillations being studied from getting directly into the crystal filter, which splits up the oscillation spectrum.

The preliminary filter is made of T-type sections. The filter uniformly passes a frequency passband of from 10 Hz to 8.5 KHz. The output of the filter is connected to the grid of the cathode follower. The mixer is designed in a ring circuit configuration, and its input is connected to the cathode follower. The intermediate frequency in the circuit considered here is chosen at f_{if} = 12.5 KHz. The crystal filter is tuned to this frequency.

The crystal filter consists of two sections, each of which is designed around a resistor phase inversion stage. The crystal is inserted in one arm of the stage, while a semivariable capacitor, which neutralizes the parasitic capacity of the crystal, is inserted in the other arm. When the resonant frequency of the crystal of the first section differs from the second one by 2 - 2.5 Hz, a passband of 4 Hz can be obtained. For the analysis of a frequency spectrum from 10 Hz to 8.5 KHz, the frequency of the audio generator is varied from 12,500 to 21,000 Hz.

The voltage from the output of the filter is amplified by a single-stage tuned amplifier and is then measured by an external vaccum tube voltmeter. Resonators with a different resonant can also be used in similar accessories. In accordance with this, the passband of the filter and the spectral range of frequencies being studied can be changed.

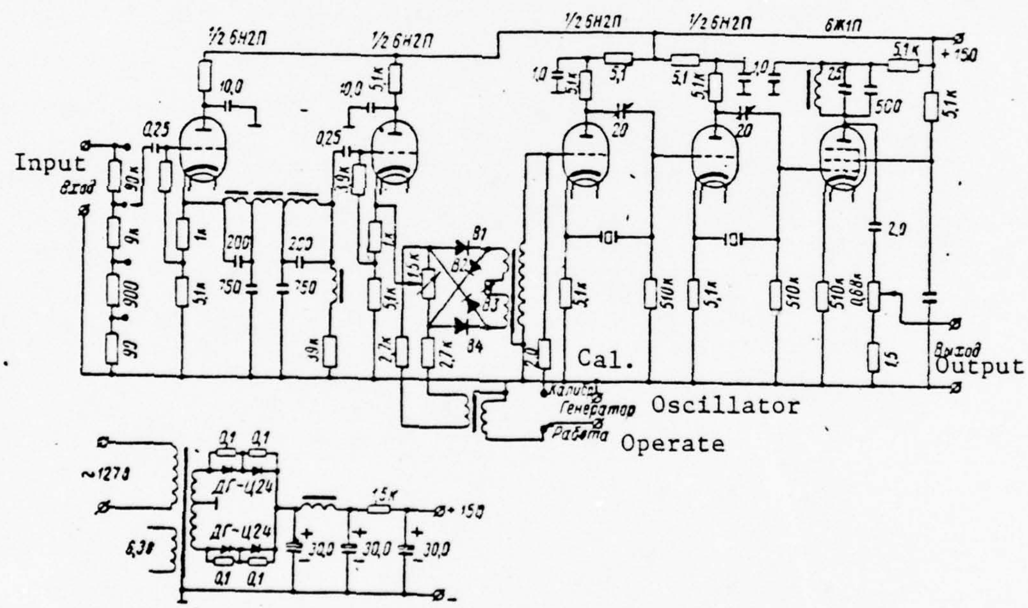


Figure 69. Audio frequency spectrum analyzer.

38. Calibrating a Frequency Spectrum Analyzer.

Shown in Figure 70 is a circuit which is used when calibrating frequency

spectrum analyzer. The oscillator used for the calibrations should have continuous frequency control and permit the readout of small frequency changes. The oscillator should deliver a purely sinusoidal current.

Figure 70. Circuit for calibrating a frequency spectrum analyzer.
Key: 1. Audio frequency generator; 2. Voltage divider; 3. Frequency spectrum analyzer.

The main thing in the calibration is the determination of the sensitivity of the analyzer at different frequencies. Determined in this case are: 1) the average sensitivity within the limits of the passband of the selective system; 2) the limiting frequencies $f_{initial}$ and f_{final} of each selective system; 3) the attenuation outside the passband of the selective system.

Thereafter, the signal level at which nonlinear distortions arise is determined. These distortions create oscillations which are absent in the frequency spectrum being studied, and are thereby a source of error. A no less important parameter which is to be determined is the range of frequencies being analyzed. Simultaneously determined during the calibration is the analysis time in the specified range of frequencies. The calibration procedure for the parameters enumerated above can vary; it is described to an adequate extent in the literature on radio measurements.

CHAPTER EIGHT

Cathode Ray Tube Spectrometer Systems and Their Construction

The spectrum analysis of aperiodic oscillations is accomplished with spectrometers. These instruments permit the observation of the spectrum of different

oscillations on the screen of a cathode ray tube. Spectrometers have a comparatively wide band frequency selective system, because of which the precision of this spectral analysis of the frequencies is less than for harmonic analyzers.

39. The Specific Features of Spectrometers

The operational principle of a cathode ray tube spectrometer is similar to that for the operation of a harmonic analyzer. Used in both of them are an analyzing device and a recorder. To convert an analyzer to a spectrometer, it is necessary to additionally realize the following: 1) the automatic analysis of the oscillations; 2) the simultaneous observation of all or part of the spectrum of the oscillations being investigated. These requirements should be met during the limited analysis time of the oscillations. Such an analysis is realized using an automatic analyzer.

Automatic analysis permits the recording and simultaneous observation of all components of an oscillation. The decrease in the analysis time makes it necessary to have a wide passband for the selective system, and thereby degrades the differentiation capability of the instrument.

The choice of the analysis time and the passband is important in designing spectrometers. An effort is practically always made to find compromise solution between the necessity of narrowing the passband of the selective system to increase the resolving power of the instruments and a convenient analysis time for the simultaneous viewing of the spectrum. With a small analysis time, the readout of the components of a complex signal can be realized by means of an inertialess recording device.

Of the systems of recording devices, these requirements are satisfied best of all by a CRT. The concept behind this device consists in the fact that the voltage to be measured is fed through the vertical deflecting plates of a CRT, while a sawtooth voltage which effects the linear scanning of the voltage being measured is fed to the horizontal plates. The height of a section is a measure of the magnitude of the amplitude of the oscillation being studied.

The frequency of the oscillation component is determined based on the position of the amplitude on the abscissa axis; a frequency scale can be assigned to the sweep.

Image scanning. To simultaneously observe the entire spectrum of the oscillations being studied, the sweep rate should be such that the eye does not notice flickering. The sweep rate of the image depends on the analysis time and the permissible quality for visual observation.

The start of the sweep should correspond to the start of the frequency readout of the oscillations being studied and occupy a strictly constant position on the graduated scale. The end of the sweep should correspond to the end of the frequency readout for the specified frequency range. Due to persistence of vision, our vision is capable of preserving what has been seen for 0.1 seconds. For this reason, oscillations repeating at this rate will seem stationary. The slower the sweep rate, the greater the image flicker will be.

At a sweep rate of 25 - 50 periods per second, flickering disappears. In those cases where the analysis time should be small, cathode ray tube with screen persistence are used for viewing the spectrum. The persistence time should be such that by the end of the analysis the spectral lines located at the start of the screen are visible.

40. Analysis Methods in Spectrometers

A large number of different types of spectrometers exist. Depending on the requirements made on the precision in the determination of the spectrum and on the image quality, either sequential or simultaneous analysis of the oscillation is employed. Shown in Figure 71 is a block diagram of a heterodyne type spectrometer which sequentially analyzes the oscillations. The oscillations are analyzed in the following fashion. Fed to the mixer is the voltage of the oscillation being studied and the voltage from the heterodyne oscillator.

If the frequency of the oscillation being studied is equal to f_c, while the heterodyne frequency is f_h, then the combination frequencies $2f_c$ and $2f_h$, as well as the sidebands $f_c + f_h$ and $f_c - f_h$, etc., appear as a result of the mixing. A filter, which is inserted following the mixer, is tuned to one of the side intermediate frequencies. With each component of the spectrum being studied, the heterodyne frequency sequentially yields an intermediate frequency.

The voltage from the output of the filter is detected after being amplified and is fed to the vertical deflection amplifier, and from there to the vertical deflection plates of the CRT. The sawtooth voltage from the sweep oscillator is simultaneously fed to the deflecting plates of the CRT and to the reactance tube which modulates the heterodyne frequency. Because of this, a set position of the beam along the horizontal of the CRT screen corresponds to each instantaneous value of the heterodyne frequency. The sweep generator frequency is varied in accordance with a sawtooth law with a very small retrace time.

The deflection of the heterodyne frequency should correspond to the range of the spectrum being studied. The image of the spectrum being studied appears on the screen of the CRT in the form of individual sections. If the tube has sufficient screen persistence, then the image of the first sections of the spectrum is preserved until the scanning of the entire spectrum is completed.

Variants exist for the analysis heterodyne circuits, which differ from each other in the method of intermediate frequency conversion and the method of scanning on the frequency axis.

Pictured in Figure 72 as an example of one of the modifications of the circuit considered here is a block diagram with dual frequency conversion. The signal being studied is fed through mixer 1, where it is mixed with a signal from the frequency modulated oscillator (ChMG), the frequency of which varies within limits of 50 - 70 KHz. The variation of the frequency modulated oscillator frequency is accomplished by a modulator tube, to which the sawtooth voltage

is fed from the sawtooth generator. The difference frequencies appearing at the output of the mixer are isolated by a selective amplifier at 50 KHz.

The second conversion makes it possible to increase the resolving power of the spectrometer. For this, the 50 KHz frequency is mixed with a frequency of 47 KHz from an auxiliary oscillator in mixer 2. The difference frequencies which arise are fed to a selective amplifier with a very narrow passband.

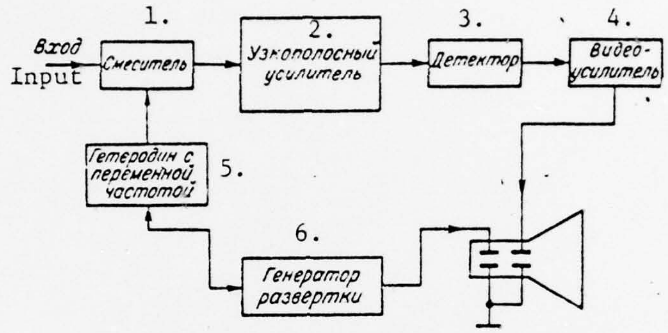


Figure 71. Block diagram of a heterodyne type spectrometer.

Key: 1. Mixer; 2. Narrow-band amplifier; 3. Detector; 4. Video amplifier; 5. Variable frequency heterodyne oscillator; 6. Sweep generator.

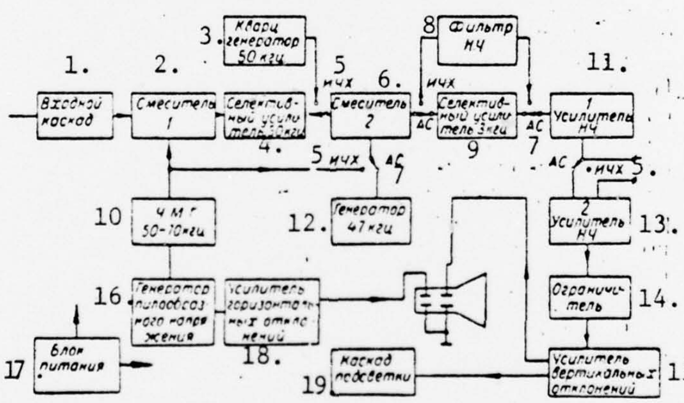


Figure 72. Block diagram of a spectrometer with dual frequency conversion.

Key: 1. Input stage; 2. Mixer 1; 3. 50 KHz crystal oscillator;

4. 50 KHz selective amplifier; 5. IChKh, frequency response display set; 6. Mixer 2; 7. AF, frequency spectrum analysis;

Key to Figure 72 continued: 8. Low frequency filter; 9. 3 KHz selective amplifier; 10. 50 - 70 KHz frequency modulated oscillator; 11. Low frequency amplifier 1; 12. 47 KHz oscillator; 13. Low frequency amplifier 2; 14. Limiter; 15. Vertical deflection amplifier; 16. Sawtooth generator; 17. Power supply block; 18. Horizontal deflection amplifier; 19. Light bias stage.

The resulting oscillations are amplified, fed to a half wave limiter, and from there are fed to the input of the vertical amplifier and then go on to the vertical deflection plates of the cathode ray tube. A stationary image of the frequency spectrum is obtained on the screen of the CRT. Frequency synchronization is realized by simultaneously feeding the sawtooth voltage to the modulator of the frequency modulated oscillator and to the horizontal deflection amplifier for the image on the CRT screen.

A block diagram of a spectrometer, which realizes the simultaneous analysis of a signal, is depicted in Figure 73. The concept behind this method consists in simultaneously passing the various segments of a spectrum of a complex signal through a set of filters tuned to the different frequencies. The band width of each of the filters is 1/3 octave.

Shown in Figure 74 are the attenuation curves for the filters used in the spectrometer. It can be seen from these curves that the system of filters is suitable for a rough analysis of the signal.

The operational principle of the instrument considered here consists in the following. There is a diode rectifier at the output of each filter. The rectified voltage is proportional to the effective value of those components, the frequency range of which is passed by the given filter. This voltage is fed in turn to the input of the frequency converter by means of a switch. The heterodyne frequency is f_h = 3 KHz. At the output of the converter there will be a voltage with amplitude proportional to the voltage of the connected

filter. This voltage is passed through the bandpass filter, the amplifier, and the detector.

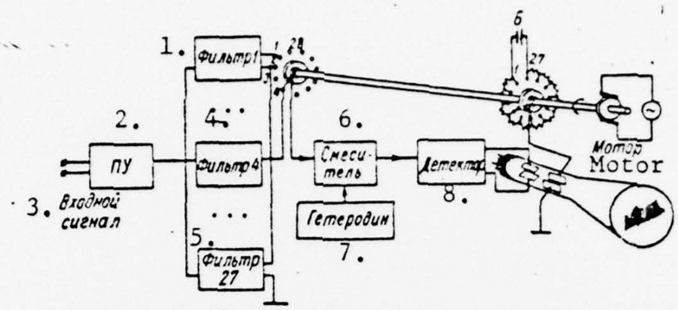


Figure 73. Block diagram of a simultaneous analysis spectrometer.

Key: 1. Filter 1; 2. Preamplifier; 3. Input signal; 4. Filter 4;
5. Filter 27; 6. Mixer; 7. Heterodyne oscillator; 8. Detector.

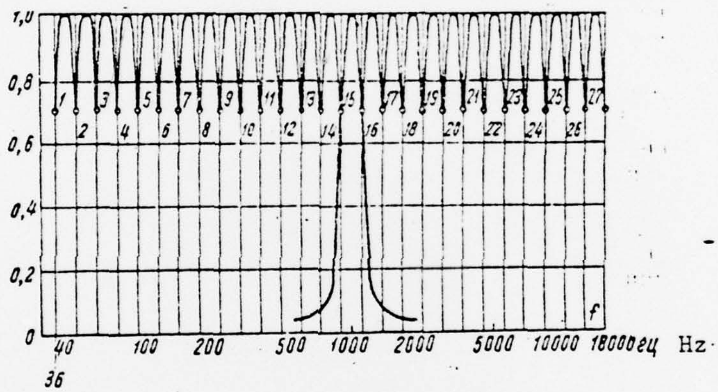


Figure 74. Attenuation curve for the filters in the spectrometer.

From the detector, the voltage is fed to the deflecting plates of the CRT. An image is obtained on the screen of the CRT in the form of vertical lines, the magnitude of which is proportional to the voltage coming from each filter. The magnitude of the constant voltage fed to the horizontal detecting plate of the CRT is varied synchronously with the switching of the filters in equal steps. The change in the sweep voltage yields a horizontal shift of the light beam on the screen of the CRT. A set position of the beam along the horizontal on the CRT screen corresponds to each filter.

The analysis time is determined by three factors: The settling time for the current in the filters, the charging time for the storage capacitors in the filter, and the time for one complete discharging of these capacitors.

The author of this book has proposed a heterodyne-filter method for the analysis of infrasound frequencies using a spectrometer.

41. Panoramic Sweep Methods

Mechanical, electrical, and other types of scanning can be employed in a CRT spectroscope. A motorized system is employed in mechanical scanning; the slide of a potentiometer is fitted on the motor shaft. The potentiometer is made in the form of a ring. With the heterodyne analysis method, also fitted to the motor shaft is a variable capacitor, which controls the frequency of the heterodyne oscillator. The voltage picked off from the potentiometer will vary proportionally to the angle of slide rotation; when the slide reaches the center of the potentiometer, the sweep voltage drops to zero. With a further rotation of the slide, the voltage increases.

With a maximum voltage applied to the horizontal deflecting plate of the CRT, the electron beam is in the position from which the frequency readout of the spectrum being studied starts. With a decrease in the sweep voltage, the electron beam approaches the center, and then, in passing through zero, the voltage takes on a negative polarity and goes to the other side of the screen.

The voltage fed to the deflecting plate is equal to half of the power supply voltage. Obviously, the frequency scale in such a device can be established by both the shape of the capacitor plates, and the law governing the distribution of the voltage drops across the sweep resistance. The scale of the frequency axis can be regulated by the sweep voltage. Let us assume that two components are visible on the screen of the CRT with frequencies so close that they almost merge. By increasing the sweep scale for the frequency axis, one can seperate both signals. At a high motor rotation speed, the potentiometer resistors

rapidly wear out and fail because of friction.

Electronic methods of panoramic sweep can be the most diverse. The majority of them are realized by devices consisting of a sawtooth generator and a sweep amplifier. The sawtooth voltage is fed through the sweep amplifier to the horizontal deflection plates of a CRT, and simultaneously to the frequency modulator of the heterodyne stage. Such a circuit permits varying the heterodyne frequency simultaneously with the horizontal travel of the beam. Because of this, corresponding to each position of the spot on the horizontal axis of the screen is a set frequency for the signal fed to the mixer. A single tube transitron oscillator can serve as a source of the sawtooth voltage.

The following main requirements are placed on panoramic sweep: 1) The voltage from the output of the sweep amplifier should be symmetrical and sufficient for beam deflection by an amount equal to the diameter of the CRT screen; 2) The capability of moving the beam along the horizontal; 3) An adjustment for the scale of the frequency axis should be provided.

42. The Conditions for the Selection of the Main Parameters of a Spectrometer

The primary parameter of a spectrometer is the analysis time. While the signal analysis in harmonic analyzers can continue for a relatively long time, a limited time is needed in spectrometers to view the entire signal spectrum. In order not to distort the spectrum of the oscillations being studied, the analysis time τ should be significantly less than the duration of the oscillations being studied, i.e. 1/t, where t is the duration of the oscillations being studied. This requirement is unfeasible when the resolving power of the instrument is high.

Introduced in spectrometers is the concept of *instrument resolving power*, which is defined as the resolving powers of the resonator and the CRT. The resolving power of the later is taken as: $\gamma = \frac{d(f_1 - f_2)}{l}$;

i.e. the ratio of the product of the diameter d of the electron spot made on the screen of the CRT and the frequency range covering the working length l of the screen to the length, l.

Considering the fact that each passband Δf which can be passed by the filters creates markers along a vertical line which are $\Delta l = d$, it is easy to determine the frequency spectrum $f_1 - f_2$ which can be positioned in a set length on the CRT screen:

$$\frac{d}{l} = \frac{\Delta f}{f_1 - f_2}.$$

Specifying the working length of the CRT screen as $l = 200$ mm, the beam width as $\Delta l = 1$ mm, and the passband as $\Delta f = 50$ Hz, we find that the frequency spectrum markers which can be positioned on the screen are: $f_1 - f_2 = (50 \cdot 200) : 1 = 10{,}000$ Hz. Consequently, the resolving power of the instrument is such that for the specified passband of the filter, one can analyze a frequency spectrum up to 10,000 Hz. The passband of the selective system in the spectrometer should be no less than the scale of the frequency axis.

In order that the frequency spectrum analysis using the sequential methods is not distorted, the following time is required:

$$t = \frac{1{,}4\,(f_1 - f_2)}{(\Delta f)^2} = \frac{1{,}4 \cdot 10\,000}{2500} \approx 60 \text{ сек.}$$

The resultant analysis time is insufficient for the simultaneous viewing of the entire spectrum. The engineering solution of this problem can be accomplished by using a CRT with a greater screen persistence. Using the tracers of lines on the CRT screen, the entire spectrum being analyzed can be displayed. One can take recourse to such a procedure only when $\tau >> 1/t$, i.e. when the analysis of time is significantly less than the duration of the oscillations being studied. This requirement is a basic condition in the design of spectrometers. The analysis time should be shorter than the duration of the process being studied.

Two other questions are to be subsequently resolved in the design of a spectrometer: The determination of the optimum passband and the permissible

selectivity of the system.

In choosing the passband, it is essential to take into account not only the resolving power of the CRT, but also the time needed to establish the amplitudes of the harmonic components in the filter. This question has already been treated in § 16. If the analyzable passband is equal to $f_1 - f_2$, and the method of simultaneous analysis is selected, then the passband of each filter is taken as $\Delta f = (f_1 - f_2)/n$, where n is the number of filters.

The choice of the selective system depends on the requirements made as regards the frequency range, precision in the determination of the spectrum, and operational convenience. To be taken into account here are the considerations set forth in § 15.

A spectrum analyzer in a complex with an automatic level recorder or a dual coordinate autorecorder forms a system for the automatic recording of the frequency spectra on graduated chart paper. The drive for the chart travel on the automatic level recorder should be synchronized with the sweep frequency of the analyzer.

The measurement result is represented in the form of a "frequency - amplitude" diagram of the signal being measured.

43. A Spectrometer for the Infrasound Frequency Range

The spectrometer described here makes it possible to analyze the spectrum of an electrical signal in a frequency range of from 0.88 up to 142.5 Hz. The oscillation being analyzed is fed to the input of the spectrometer, is amplified by the amplifier, and goes to the one-third octave filters. These are the filters in analyzer 22.

Two types of filters are used in the spectrometer: LC section and RC section filters. The LC section filters consist of two asymmetrical M-sections, in-

serted in series. The voltage from the output of the filters is fed through the detector, which is built-up using a microminature 6D6A diode, and then goes to the mechanical switcher.

The mechanical switcher serves for the alternate, periodic switching of the outputs of the filter to the input of the modulator unit. The rotational speed of the switcher is 167 r.p.m.

In the modulator unit, the DC pulses modulate a frequency of 8,000 Hz. The modulated signals pass through the detecting unit, are amplified by the vertical sweep amplifiers, and fed to the plates of the CRT, which is the display for the electronic marker block.

The maximum sensitivity of the spectrometer when the beam is deflected over the entire height of the screen for a sinusoidal voltage at a frequency corresponding to the center frequency of each filter is 15 dB. The spectrometer is equipped with a photographic accessory, which makes it possible to photograph the spectrograms in the form of individual frames, as well as to take continuous pictures at a rate of 65 ± 5 frames per minute.

44. An Audio Spectrometer

Shown in Figure 75 is the functional schematic of a FSP-10 type spectrum analyzer. This instrument performs the spectral analysis of transient oscillations in a frequency range from 36 Hz to 18 KHz in a time on the order of 0.1 sec. All spectrum components appear simultaneously on the screen of the CRT.

The operational principle of the instrument. The voltage fed to the input of the spectrometer through the seven-step divider (1:1000) is fed to the amplifier, Us. This amplifier takes the form of a two tube resistance coupled stage. The first stage is a standard amplifier, and the second is a cathode follower, KP. Connected in parallel with the load on the cathode follower are 36 bandpass filters of identical relative transmittance band.

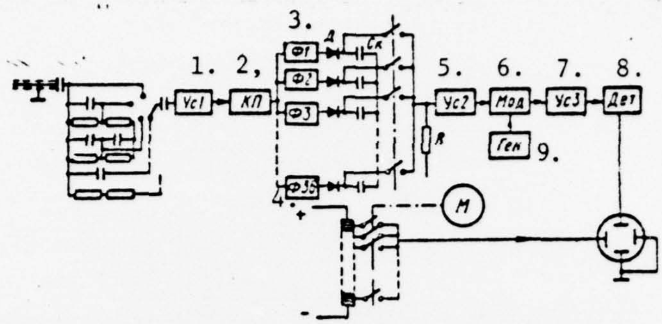


Figure 75. Functional schematic of the FSP-10 spectrum analyzer.
Key: 1. Amplifier 1; 2. Cathode follower; 3, 4. Filters 1-36; 5. Amplifier 2; 6. Modulator; 7. Amplifier 3; 8. Detector; 9. Oscillator.

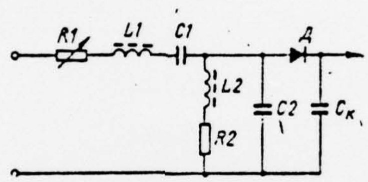


Figure 76. Circuit of the FSP-10 spectrometer filter.

The circuit of the filters is shown in Figure 76; it is designed in a half-T-section configuration. The voltage picked off from the cathode filter, is rectified and stored in capacitors Ck. This EC voltage is alternately picked off by the switcher from each filter and fed to the amplifier Us 2. The commutator rotor with the brushes is rotated by an electric motor at a speed of 1,350 r.p.m. At this switching speed, the image on the screen of the CRT appears stationary.

The circuit of the commutator has a three row contact system with 40 contacts per row. The voltage from the amplifier output modulates the carrier frequency, Mod, arriving from the special oscillator, Gen. The modulated voltage is additionally amplified by Us 3 and then detected. The voltage from the detector is sent to the vertical deflection plates of the CRT. The height of each beam deflection corresponds to the amplitude of a component of the spectrum.

The voltage, picked off by the contacts of the inside row of the commutator, deflects the electron beam along the horizontal synchronously with the switching of the filters. Corresponding to each contact is a set position of the lighted spot on the screen of the CRT.

The values of the horizontal deflection voltage are set so that, besides the 36 points corresponding to the number of filters, there are 4 more additional points at the right side of the screen. These points are reference points for determining the amplitude, based on height, of the values being measured of the spectrum components of the oscillations being studied. The 36 points are subdivided into groups of 4 points each per octave. Each group is spaced apart from the other by an increased interval. The output amplifier, Us3, operates as a logarithmic amplifier which permits deriving the amplitude of the signal components on a logarithmic scale.

45. The ASChKh-1 Spectrum Analyzer

The ASChKh-1 spectrum analyzer is a sequential analysis spectrometer; the instrument works on the dual heterodyne principle. The spectrometer is intended for observing and investigating a spectrum from 20 to 20,000 Hz. The frequency spectrum is studied in subranges: The first subrange is from 20 to 500 Hz; the second is from 60 to 2,000 Hz; the third is from 100 to 5,000 Hz; the fourth is from 400 to 20,000 Hz. The technical conditions for this instrument are given in § 36. A skeleton schematic of the instrument is shown in Figure 72.

The instrument design. The voltage being studied is fed through the input of a cathode follower. There is a voltage divider at the input to this stage. The voltage is fed from the cathode follower to the first mixer. The mixer is designed in a ring circuit using crystal diodes. In the mixer, the voltage being studied is mixed with the voltage of a frequency modulated oscillator, the frequency of which varies in limits of 50 - 70 KHz. The difference frequencies which appear at the output of the mixer are fed to the input of the selective amplifier. Potentiometers R1 and R2 (Figure 77) are used to balance

mixer (suppress the 50 KHz carrier frequency). The carrier frequency cannot be completely suppressed, and this is revealed on the CRT screen in the form of a small amplitude overshoot right at the start of the frequency axis.

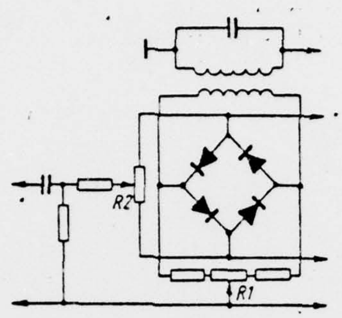


Figure 77. Circuit for balancing the mixer.

The selective element of the selective amplifier is a dual, RC, T-section filter, tuned to a frequency of 50 KHz; its passband is 500 Hz. The frequency modulator oscillator is a standard RC oscillator, which is modulated by varying the internal resistance of the 6K4T tube, which is connected in parallel with the RC network of the oscillator. If the voltages changed at the first grid of this tube, its internal impedance changes, and thus, the frequency of the oscillator is modulated.

To obtain a higher resolving power of the instrument, a second conversion of the frequency being studied is introduced. Fed through the input of the second mixer from the output of the selective amplifier is a voltage at a frequency of 50 KHz, and one at a frequency of 47 KHz from the second heterodyne stage. Following conversion, the difference frequency of 3 KHz is seperated out by the 3 KHz selective amplifier. This selective amplifier is designed in a twin T-section bridge circuit in a manner analogous to that for the 50 KHz selective amplifier.

The amplifier passband is 4-5 Hz. The further amplification is accomplished by two stages. There is a potentiometer in the circuit of the control grid to regulate the output signal level on the CRT screen. The voltage being

analyzed is fed to a limiter diode, which cuts off one-half of the signal period. Because of this, visible on the CRT screen is the spectrum line for only one sign, i.e. on one side of the sweep line. After limiting, the oscillation spectrum is amplified in the vertical deflection amplifier. The displacement of the beam along the vertical axis of the CRT screen is accomplished by the potentiometer.

The frequency modulated oscillator used in the spectrum analyzer is a standard RC oscillator. The variation (sweep) of the oscillator frequency is accomplished by a sawtooth voltage. The oscillator is modulated by varying the internal resistance of a 6K4T reactance tube, which is connected in parallel with the RC circuit of the oscillator. Varying the voltage at the first grid of this tube changes its internal resistance, and in this way effects the modulation.

To obtain the selected frequency scales in each subrange, the frequency of the FM oscillator is swept within the following limits: 1) 50-50.5 KHz; 2) 50-52 KHz; 3) 50-55 KHz; 4) 50-70 KHz. This switching of the scales is realized by varying the amplitude of the sawtooth voltage which is fed through the grid of the modulator tube by means of the potentiometer. The initial frequency is set by potentiometers.

The sawtooth generator modulates the frequency modulated oscillator and simultaneously scans the image along the horizontal axis of the CRT. This oscillator is a thyratron relaxation oscillator, in which the discharge takes place through a 6Zh8 charging tube, while the discharge takes place through the thyratron. Changing the sweep rate is realized by means of a potentiometer located in the green grid circuit of the charging tube.

The sawtooth voltage is fed through the input of the horizontal deflection amplifier, which is designed in a circuit configuration similar to that of the vertical deflection amplifier. The electron beam can be moved along the horizontal on the CRT by means of a potentiometer inserted in the grid circuit

of the horizontal deflection amplifier tube. To obtain a brighter and higher quality image, a provision is made in the instrument circuit for beam bias lighting during the measurement process. The frequency spectrum analyzer is made in the form of two individual modules: The analyzer module and the power supply module. The power supply module contains a ferroresonant regulator for the filament supply for all tubes, and four rectifiers.

A spectrometer which analyzes transient oscillations.

Shown in Figure 78 is a block diagram of a spectrometer working on the simultaneous analysis principle. This circuit is a modernized variant (see Figure 73) of that treated in § 40. In this circuit, the electronic commutator performs 60 filter switching operations per second.

The spectrometer operates in the following fashion: The oscillation being studied is simultaneously fed to the input of the 28 channels: Each of 27 channels contains a filter with a band width of 1/3 octave, an amplifier and a rectifier; the 28th channel passes the entire spectrum of the oscillations being studied. The rectified voltage from each filter is fed to an output circuit by means of the electronic switcher. There are 30 switching positions in the commutator. The two additional positions are used for synchronization.

The electronic switcher also acts on the sweep generator, and following the switching series, returns the electron beam to the initial position. The voltage from the output circuit is fed to the vertical deflection plates of the CRT. The beam is horizontally deflected by a ladder - form voltage, having 30 steps. This voltage is generated in a special "ladder generator", which is controlled by the main pulse generator and the electronic switcher.

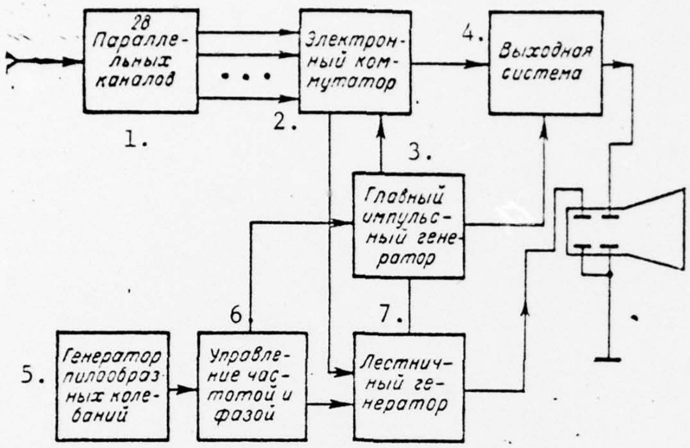


Figure 78. Block diagram of a spectrometer operating on the principle of simultaneous analysis.

Key: 1. 28 parallel channels; 2. Electronic switcher; 3. Main pulse generator; 4. Output system; 5. Sawtooth generator; 6. Frequency and phase control; 7. Ladder generator.